The 51 m-high Woodstock Dam has a gross storage capacity of 381 million m³.

Lani van Vuuren

THUKELA-VAAL TRANSFER SCHEME: Feeding the Hungry Heartland

Thirty years on, the Thukela-Vaal Transfer Scheme, which pumps millions of litres of water from the resource-rich Thukela catchment up and over the Drakensberg escarpment to the water-stressed Vaal, is still regarded as one of South Africa's engineering marvels. Compiled by Lani van Vuuren.

The 1960s were a decade of unprecedented economic growth in South Africa. Between 1962 and 1967 the average growth rate in the production of services and goods was 6,3%. Most of this growth was in the economic heartland of the country (then known as the Pretoria-Witwatersrand-Vereeniging complex). As economic growth took place the demand for water grew. The area received most of its water from the Vaal River system, which was by then already a hard working river.

Other large users of the Vaal River's resources included Sasol, Iscor (known today as Arcelor Mittal South Africa), the Electricity Supply Commission (Eskom), Orange Free State Goldfields, Western Transvaal Regional Water Company (known today as the Midvaal Water Company), the Vaal-Gamagara Government Water Scheme, the Vaalhartz irrigation scheme and various towns.

Drought conditions experienced between 1960 and 1966 caused the Minister of Water Affairs to impose water restrictions in the PWV area for the first time in decades. While satisfactory rains allowed these restrictions to be lifted in February 1967, they were re-imposed from February to November 1969. Between October 1970 and November 1971 and in 1973 the area also faced restrictions, contributing to the stagnation of industrial investment in the region.

At that stage the storage capacity of the storage schemes on the main stem of the Vaal River was 4 100 million m^3, capable of supplying 1 545 million m^3/year on a dependable basis. However, the demand for water from the Vaal was to reach 1 600 million m^3/year by 1976, and the realisation dawned on authorities that something needed to be done.

ALL EYES ON OTHER CATCHMENTS

In a paper published in *The Civil Engineer in South Africa* in August 1982 TPC Robbroeck, then Managing Engineer (Water Resources) in the Department of Water Affairs (DWA) wrote: "Apart from the limited raising and strengthening of the Vaal Dam…raising of the other dams was found to be unsatisfactory and uneconomic. Most of the water that would have been gained would have been lost because of the increased surface area exposed to evaporation. Indirect re-use of water was already taking place to the fullest extent possible and the only other feasible source for augmentation was inter-basin transfer from neighbouring catchments."

By the 1960s negotiations with Lesotho to construct the Lesotho Highlands Water Project (LHWP) had already started, but was proving difficult and lengthy. In the meantime, demand kept growing. Attention subsequently became focused on the upper reaches of the Thukela River, several 100 metres below the headwaters of the Vaal and flowing in the opposite direction (towards the Indian Ocean).

Robbroeck explains that other suitable neighbouring rivers considered were the Usutu and Komati rivers, but these were already being developed for water supply to Eskom's new power stations on the eastern Highveld. The remaining neighbouring rivers were tributaries of the Limpopo, the water resources of which were already being exploited. Thus, in June 1970, the first phase of the Thukela-Vaal Transfer Scheme was approved by the then Minister of Water Affairs, Fanie Botha.

FIRST PHASE

The original layout of the scheme comprised a dam at Spioenkop, two pumping stations and a pipeline conveying water along an aqueduct (comprising 37 km of rising main, 28 km of canal, 5,5 km of inverted siphons and 12 km of tunnels) which would discharge to the basin of the proposed Java Dam on the Elands River, near Harrismith.

Construction of the Spioenkop Dam subsequently kicked off in 1968. However, when it was discovered that the proposed Java Dam would flood a large part of the then planned Qwa-Qwa National State, the scheme had to be completely replanned. A new site for the reserve storage dam was found at the farm Sterkfontein on the Nuwejaarspruit – a tributary of the Wilge River. "This site was so close to the watershed near Oliviershoek, and on such a minor tributary, that initially it was not believed possible that it could command the required 2 000 to 3 000 million m^3 capacity; the capacity curve was recalculated several times to make sure!", writes Robbroeck.

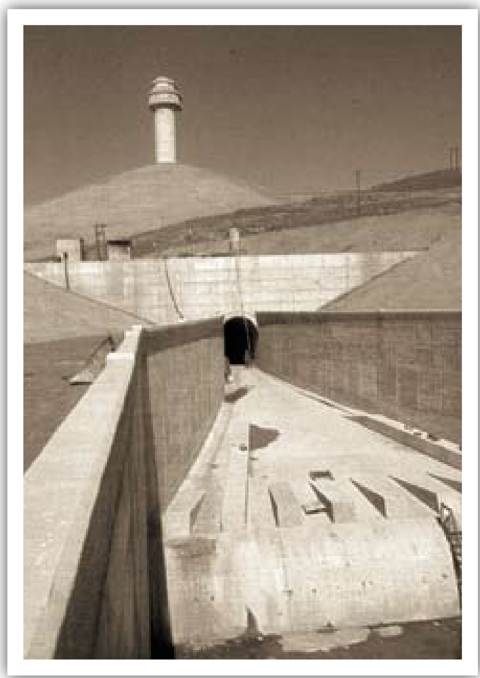
The basin was found to have a remarkable shape in that it had a wide bottom through which the river meandered at a flat gradient and was surrounded by steep slopes.


DWAF

Driekloof Dam features a concrete spillway slab with multiple baffles on the downstream slope.


DWAF

Constructed during the first phase of the Thukela-Vaal Transfer Scheme, the Driel Barrage has a capacity of 18,3 million m^3.


DWAF

The outlet works of the Sterkfontein Dam have a capacity of 220 m^3/s.

Driekloof Dam, which has been constructed across an arm of the large reservoir formed by Sterkfontein Dam.

Construction of the dam started in 1971 and at the time it was the largest earthfill embankment dam to be built in South Africa. The embankment is a typical earthfill design 2 290 m long with an impervious core sloping upstream. The dam had an original height of 68 m and a gross storage capacity of 1,2 million m^3.

The main challenge on the site was to make use of the fill materials which were quite variable (mainly weathered mudstone, shale and dolerite). This gave rise to the rather flat upstream slope. Due to its small catchment area with negligible natural inflow the dam required no spillway, which made it pretty unique.

Evaporation losses from Sterkfontein Dam are about 35 million m^3/year, which represent about 10% of the losses that would be experienced from Vaal Dam for a similar volume. When the dam was completed in 1977 it was the only dam in South Africa to qualify for inclusion in the International Commission of Large Dams (ICOLD) Register of the World's Largest Dams.

Also added to the first phase of the Thukela-Vaal Transfer Scheme was the Driel Barrage with a capacity of 18,3 million m^3 immediately below the confluence of the Mlambonja and Thukela rivers. The Spioenkop Dam would now serve to re-regulate the flow of the Thukela River for downstream users, since all the low flow was now to be abstracted at Driel.

Following the completion of the first phase in 1974, up to 330 000 m^3/day of water was lifted 506 m by means of four vertical-spindle, centrifugal pumps, each with a capacity of 110 000 m^3/day. The 3 915 m-long rising main, which varied in diameter from 1 500 mm to 1 700 mm, took the shortest route directly up the mountain to end in an aqueduct consisting of 9 350 m of canals and 1 711 m of tunnels, the main one through the watershed between the Thukela and Vaal on the aptly-named farm Tzamenkomst. This aqueduct emptied into the Sterkfontein basin. The first phase was completed at a total cost of R41,7-million.

SECOND PHASE

Meanwhile, the volume of economic activity continued to grow explosively in the PWV complex and, in 1974, the DWA proposed extending the Thukela-Vaal Transfer Scheme. Initially, the second phase was planned to increase the transfer rate to 11 m^3/s, corresponding to 950 000 m^3/day. The canals and tunnels had already been constructed to that capacity so that only the pump stations at Driel and Jagersrust would have to be duplicated as well as the associated rising mains and the Mpandweni siphon.

In addition, a further storage dam, capable of regulating the Thukela River upstream of Driel was needed to assure a constant withdrawal at the rate required. A site for such storage was found at Woodstock farm. This dam, in combination with Driel, would permit a constant 504 million m^3/year to be drawn, more than needed for the second phase.

Once completed the 51 m-high Woodstock Dam would have a gross storage capacity of 381 million m^3. For the design flood the total spillway capacity required 1 000 m^3/s, of which 500 m^3/s could be discharged through the tunnel. An additional spillway with a capacity of 500 m^3/s had therefore to be built.

Writing in the 1982 ***Civil Engineer*** HFW Elges, DWA Assistant Chief Engineer (Design) says: "This spillway was placed on the left flank and the original design comprised a straight ogee crest, a converging channel and a 15 m-wide chute discharging the water back into the river downstream of the dam. However, hydraulic model tests revealed that the waves formed in the chute were unacceptable. The solution was a curved ogee spillway section, a transition zone with a floor elevated along the centre line and an 11 m-wide chute. The energy dissipating device at the end of the chute is of the flip bucket type. An auxiliary spillway to handle floods up to 2 730 m^3/s at the dam wall was also provided on the far left flank adjacent to the chute spillway."

Construction of this embankment dam was relatively short, starting in March 1979, with river diversion in April 1980 and impounding starting in March 1982.

Before the original Thukela-Vaal Transfer Scheme phase two was adopted, investigations were carried out for a pumped storage hydroelectric scheme which would augment the water supply by allowing only a part of the pumped water to be returned for electricity generation. As a result, this phase was amended, and the Drakensberg Pumped Storage Scheme (PSS) constructed instead as a joint venture between the DWA and Eskom. The PSS would replace both the existing Jagersrust station and its proposed extension.

PUMPED STORAGE SCHEME

The increased annual quantity of water created by the PSS was to be stored in Sterkfontein Dam, and in 1980 it was decided to raise the dam to its present height of 93 m with a crest length of 3 060 m and a full supply capacity of 2 656 million m^3. The dam wall contains 17 million m^3 of fill and at that time it was the biggest earthmoving job the DWA had ever undertaken. At full level the dam is 19 km long, 6 km wide, with an average depth of 58 m. The raising was finally completed in 1986.

For the lower reservoir, or tail pool, of the PSS, a suitable site was found on the Mnjaneni River on the farm Kilburn situated at the foothills of the escarpment. The required gross storage capacity of 36 million m^3 was created by a dam 51 m high with a full supply level of . Since the water level would fluctuate over a depth of 21 m as the scheme operated, the upstream face of the dam has a flattish slope to improve its stability and is protected by rip-rap. The downstream face is grassed to combat erosion and blend in with the surrounding countryside. The dam has been operational since 1980.

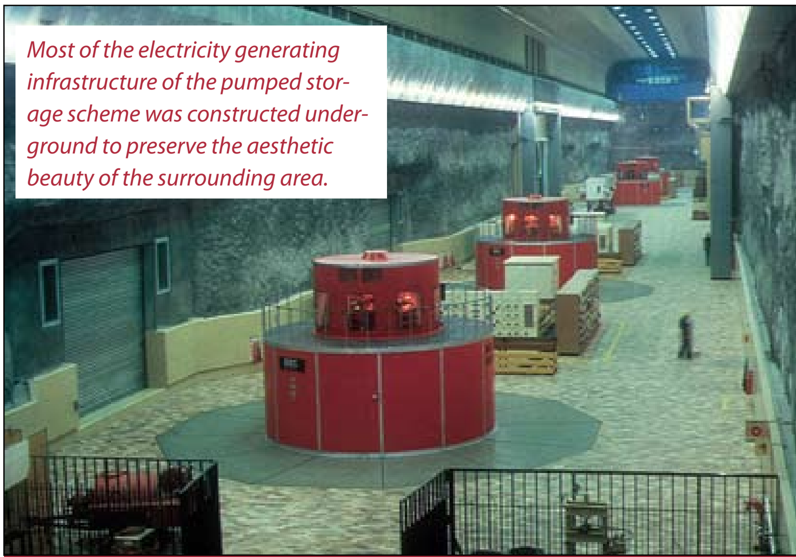
An extra pump station at Jagersrust, named the Kilburn pump station, was erected. The four 250 600 m^3/day pumps lift the water through a 2 x 1 800 mm-diameter rising main, 1 645 m long.

The upper reservoir is created by the 47 m-high Driekloof Dam constructed across one of the arms of the large reservoir formed by Sterkfontein Dam. This arrangement is rather unusual compared with other schemes in the world as the full supply level of the Sterkfontein reservoir at 1 072 m above sea level is 2 m higher than the full supply level of the Driekloof reservoir. Consequently, for about 12% of the time, the crest of the Driekloof Dam spillway is submerged and the upper 2 m of the Sterkfontein Dam used as the upper reservoir of the PSS.

In addition, the dam design was expected to handle spill either way across the wall and rapid drawdown on the upstream side. This dictated the need for a spillway across the crest. The chosen design was a rockfill dam with a central clay core and, the first of its kind in South Africa, a concrete spillway slab with multiple baffles on the downstream slope. The dam was completed in 1979.

The scheme now operates as follows: water is pumped from Driel Barrage into canals which flow via gravity into Kilburn Dam. Water from Kilburn Dam is then pumped underground, over the Drakensberg, and into Driekloof Dam. At peak periods when additional electricity is needed, water is dropped from Driekloof Dam, through the power station situated underground, and into Kilburn Dam. In quite periods, water is pumped back from Kilburn Dam and into Driekloof Dam. When the latter is full, water flows into Sterkfontein Dam, where it is stored. When water is needed in the Vaal River system, water is released from Sterkfontein Dam into the Nuwejaarspruit, which then flows into Wilge River and then into the Vaal Dam.

No sooner was the Thukela-Vaal Transfer Scheme completed than it was required to perform its water lifeline function. South Africa experienced a serious drought between 1979 and 1986.

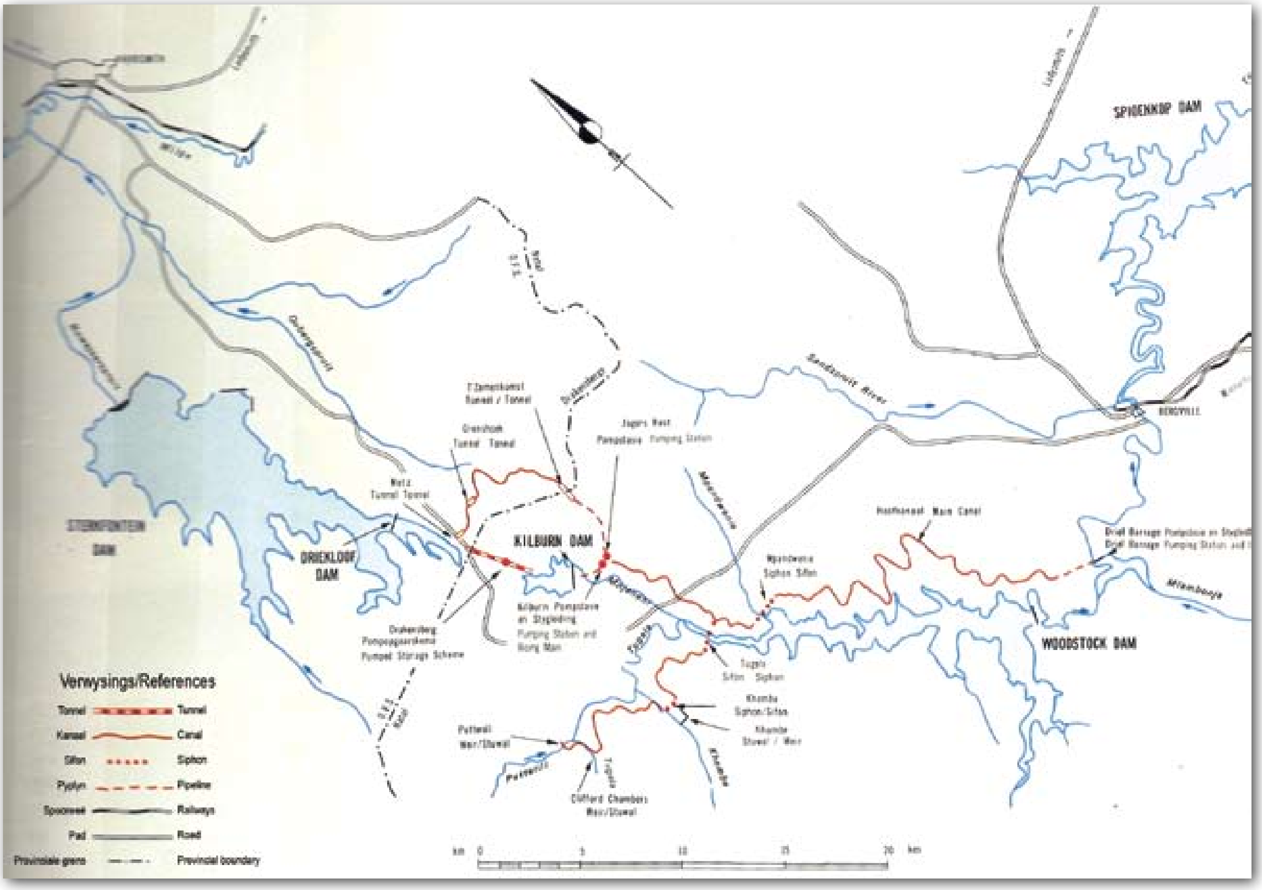


Most of the electricity generating infrastructure of the pumped storage scheme was constructed underground to preserve the aesthetic beauty of the surrounding area.

Eskom

FACTS AND FIGURES

- At the time of construction, the Drakensberg Pumped Storage Scheme had the sixth highest head in the world (473 m).
- The Sterkfontein Dam was the first South African dam to be included in the International Commission of Large Dams' register of the world's largest dams.
- During the drought of 1995, when the level of the Vaal Dam was below 15%, the transfer of water from the Thukela River to the Sterkfontein Dam and releases from this dam to the Vaal Dam were the lifeblood of Gauteng.
- The distance from Sterkfontein Dam to Vaal Dam is 370 km along the river course.
- The bottom of Sterkfontein Dam is 158 m above the bottom of Vaal Dam.
- Because of Sterkfontein's low evaporation rate, it has been calculated that every litre of water pumped into the dam from the Thukela River system makes 3 ℓ of water available from the Vaal Dam.
- In 1981, the scheme won the award as the Most Outstanding Civil Engineering Achievement from the South African Institution of Civil Engineering.



The Civil Engineer in South Africa

General Layout of the Thukela-Vaal Project.

The accumulative natural flow in the Vaal River during this time was only about 30% of the long-term average flow. By using water from the Thukela River system, serious water shortage could be averted. From 1983 to 1987 more than 1 600 million m^3 Thukela water was released which supplied about 43% of the demand during this period.

ENVIRONMENTAL CONSIDERATIONS

Up to the 1970s, there was still little pressure on dam engineers to consider the environment when planning and designing projects. Economic considerations, rather than concern for the environment, dictated when, where and how dams were constructed. Only since 1980 has it been the policy of the DWA (now the Department of Water Affairs & Forestry) to include an environmental impact assessment when planning any new infrastructure project.

From the start of the second phase of the scheme concern was expressed over the potential environmental impact of the project on the pristine area in which it was to be located. Following the announcement on 28 June 1974 by Minister Botha of the Drakensberg PSS a committee was appointed to investigate the environmental implications of the project and to make recommendations to minimise adverse effects. The committee held its first meeting on 2 October, 1974.

However, as CPR Roberts and JJ Erasmus point out in a paper published in 1982: "The project was considered to be vital from the point of view of both power generation and water supply to the industrial heart of South Africa and no other feasible alternatives had been identified. For this reason, there could be no question that the project be abandoned for environmental reasons."

However, this is probably one of the first large infrastructure projects in South Africa where concern for the environment dictated how the scheme was planned, designed and executed. For example, one of the decisions was to construct most of the electricity generating infrastructure underground to preserve the aesthetic beauty of the surrounding area. The design and construction of the large underground cavern complex in poor sedimentary rock required the services of top specialists and numerous geotechnical tests. The underground machine hall, for instance, is about 195 m long, 16 m wide and 29 m high, thus its construction was no mean feat.

Another example is Kilburn Dam, where environmental considerations dictated that the haul roads and borrow areas for the earthfill embankment and the designated tip areas for the underground power station works be situated entirely within the basin. This resulted in a congested borrow-haul-tip

One of the largest dams in the world with no spillway, Sterkfontein Dam was the first South African dam to be included in the ICOLD World Register of Dams.

configuration and spoon-picking was necessary in the available areas to get sufficient material.

In 1982, as the project was concluded, JF Otto, then DG of the Department of Environmental Affairs noted: "I am particularly pleased with the sensitive way in which the environmental issues, so important in the scenic part of our country in which the Drakensberg Project is situated have been dealt with. The creation of infrastructure brings about unavoidable disturbance of the environment. Close cooperation at an early stage between engineers, landscape architects, botanists, zoologists, and other natural scientists minimised the negative effects."

THUKELA-VAAL BETTERMENTS

From June 1988, once the first water was received from the LHWP, the Thukela-Vaal canal was shut down for two years for rehabilitation and upgrade. The so-called Thukela-Vaal Betterments project arose when it was found that the sides of the existing canal were being undermined by hydrostatic forces, caused by build-up of groundwater seeping through the surrounding soil.

The problem began when the flow in the canal was increased during the second phase of the transfer scheme. To allow for this the height of the canal was increased through the construction of an 850-mm high, vertical wall right along the top of the existing canal wall. However, this caused surface runoff water from the surrounding area to collect behind the new vertical wall. The resulting pressures and hydrostatic dynamics of the runoff water behind the wall caused it to crack and eventually subside.

During the betterments project this vertical wall was removed and the extension of the original canal sides upwards done by about 1,8 m for its entire length.

FUTURE EXPANSION

The development of water infrastructure in the Thukela River for the benefit of users in another catchment might not be over. Today, the Vaal River system is under severe pressure once again. The Integrated Vaal River System Studies, initiated by the Department of Water Affairs & Forestry in 2004, indicated that water demand from Rand Water's service area alone could reach almost 1 800 million m^3/a in 2030 from the present 1 300 million m^3/a. This, coupled with growing industrial demand from the power generation, petrochemical and steel production sectors, and severe illegal water use by irrigation farming along sections of the system, has placed the Vaal in a present water supply deficit.

At the time of writing, investigations into additional water transfer options were being finalised. Two schemes are being considered, one being further resource development in the Thukela River system (the other being a further phase of the LHWP). The two proposed dams for further development of the Thukela are one of the Bushman's River (Mielietuin Dam) and the other on the main stem of the Thukela River (Jana Dam). This could provide a nominal transferable yield of 15 m^3/s.

Since either of these projects will take a couple of years to implement, a decision regarding which project to go ahead with is expected at latest at the beginning of 2009.

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